Last Glacial Maximum over China: Sensitivities of Climate to Paleovegetation and Tibetan Ice Sheet

Dabang Jiang[1] Huijun Wang[1] Helge Drange[2] Xianmei Lang[1]

[1]Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China

[2]Nansen Environmental and Remote Sensing Center, Bergen N-5059, Norway

Three Contents:

LGM climate was firstly simulated under the common boundary conditions from PMIP [*Joussaume and Taylor, 1995*], and then compared with other AGCM outputs and reconstructed data.

After that, paleovegetation was introduced into the model to study climate response to the changes in vegetation and associated soil over China.

Also, influence of possible Ice Sheet over part of the Tibetan Plateau on the regional climate at the LGM is evaluated.

OUTLINE:

Introduction

1 IAP9L-AGCM

2 Boundary Conditions and Experimental Design

3 Simulated LGM Climate

4 Validation and Intercomparison between AGCMs

5 Paleovegetation Feedback over China

6 Role of Continent Ice Feedback over the Tibetan Plateau

Summary

INTRODUCTION:

Documenting the characteristics of past climates and understanding the causes of climatic change are major challenges for studies of the earth system [*Kutzbach et al., 1998*].

Even if models could simulate today's climate perfectly, this would not guarantee an accurate simulation of climate change [*Joussaume et al., 1999*].

The ability to correctly simulate past climates bears directly on whether we can confidently forecast future climates [*Kohfeld et al., 2000*].

Mid-Holocene and LGM have been chosen as two focuses by PMIP.

1. AGCM

IAP9L-AGCM:

$5^o \times 4^o$ (Lon by Lat);

9 Layers with top at 10-hPa

[*Zeng et al., 1987; Zhang, 1990; Bi, 1993; Liang, 1996*]

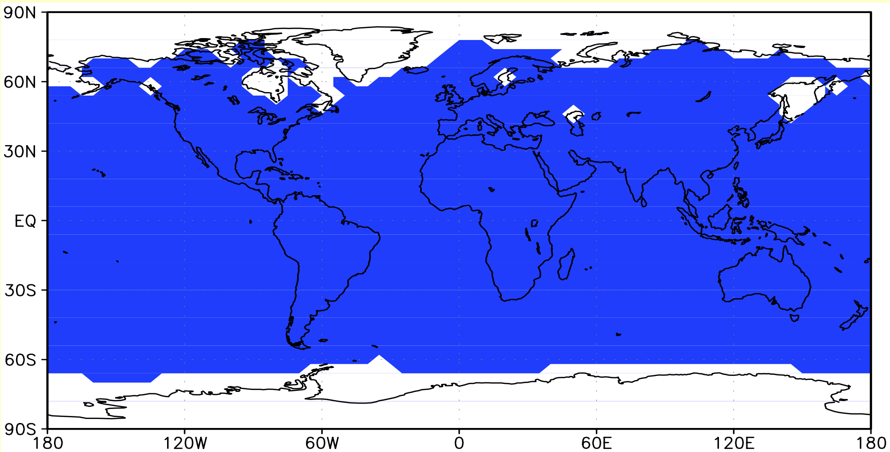
2. Boundary Conditions and Experimental Design

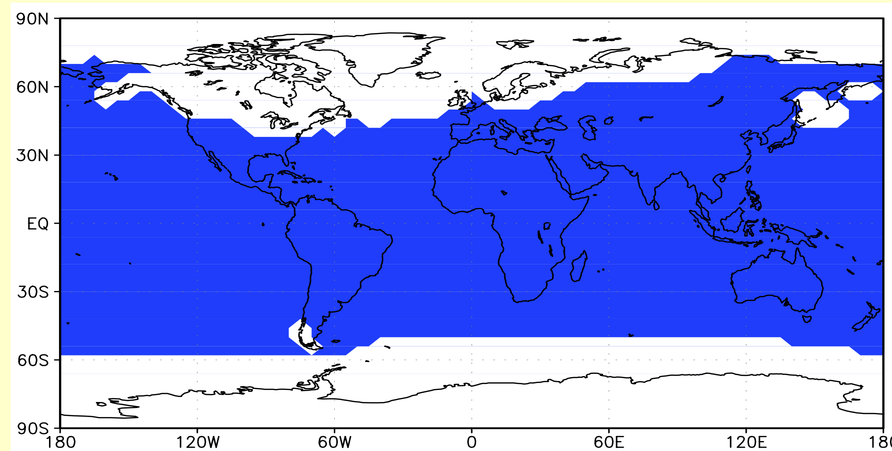
Table.1 Boundary conditions for the LGM

Time (ka)	The Earth's Orbital Parameters			CO_2 Level (ppmv)	Ice sheets & Topography & Coastline	Prescribed SSTs, Sea ice
	Eccentricity	Obliquity	Longitude of Perihelion			
0	0.016724	23.446°	102.039°	345	PD	PD
21	0.018994	22.949°	114.425°	200	*Peltier [1994]*	*CLIMAP [1981]*

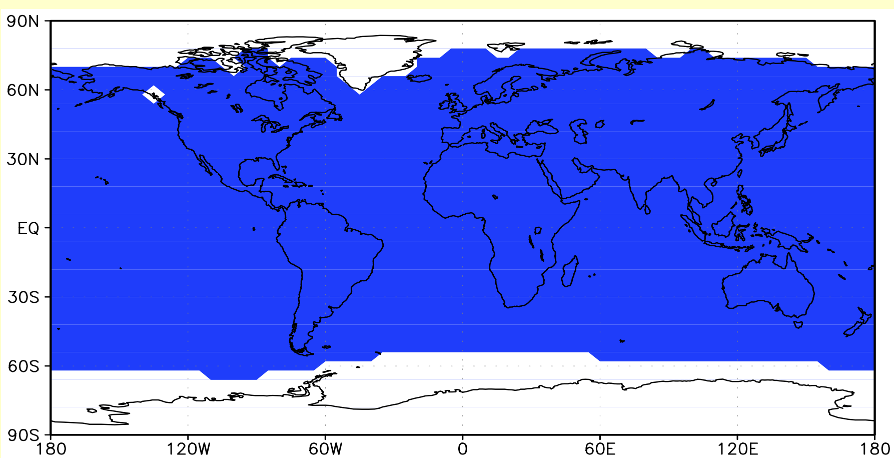
Continental-Sea Ice Distribution

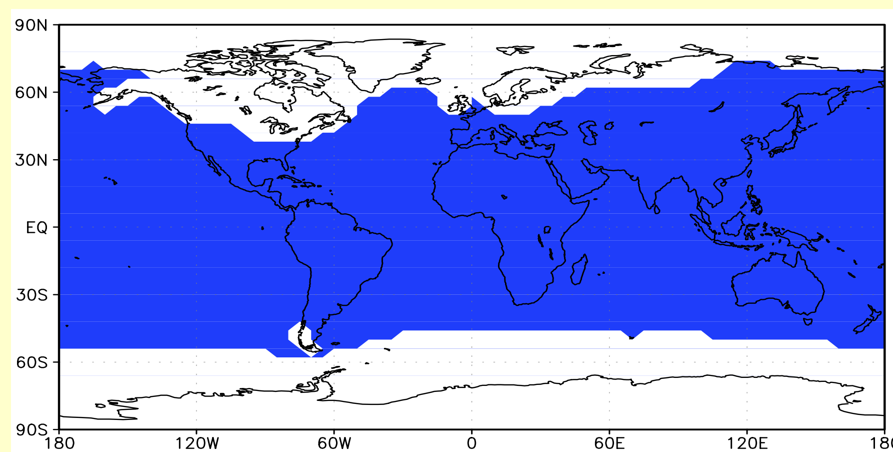
PD	LGM





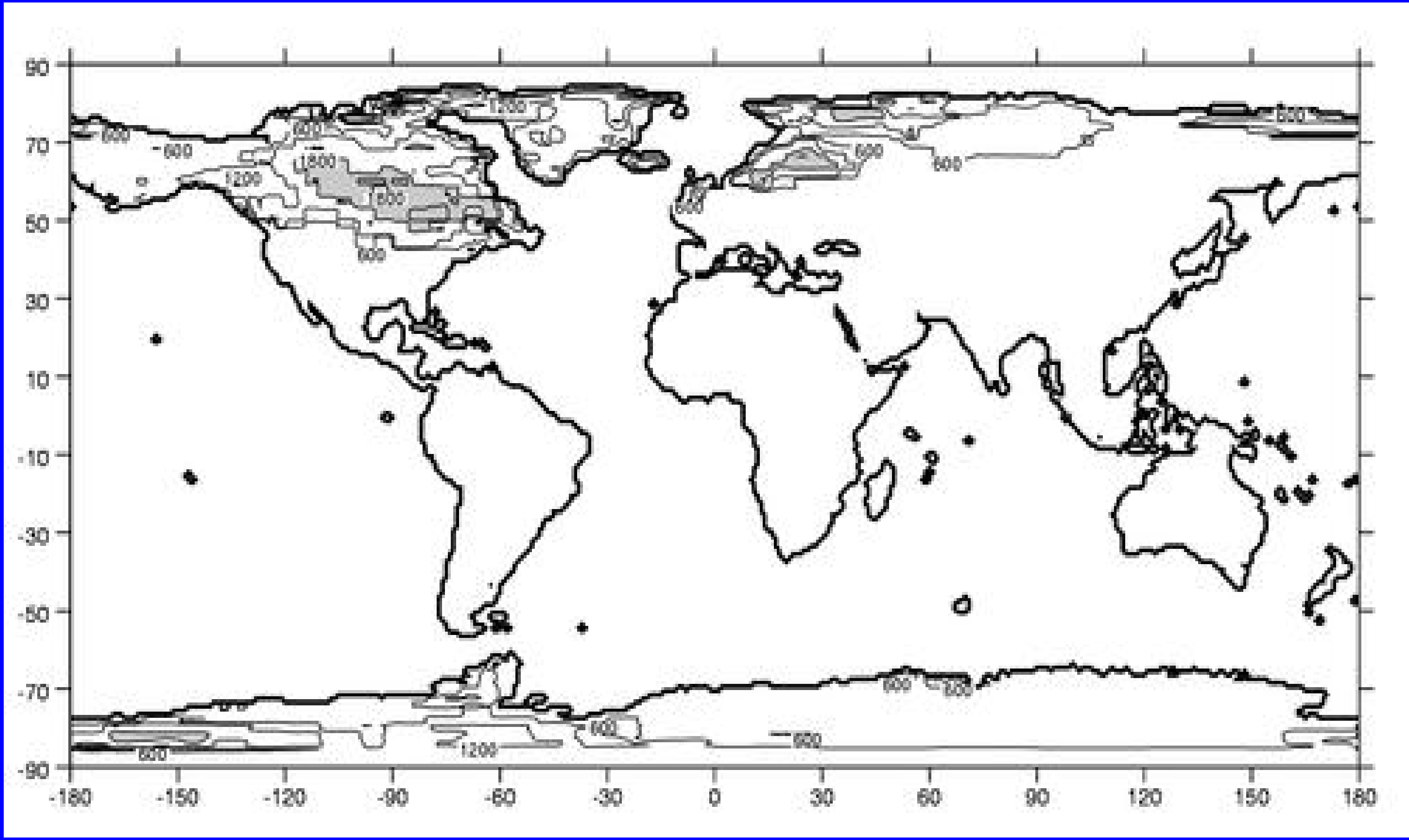
Feb.	Feb.





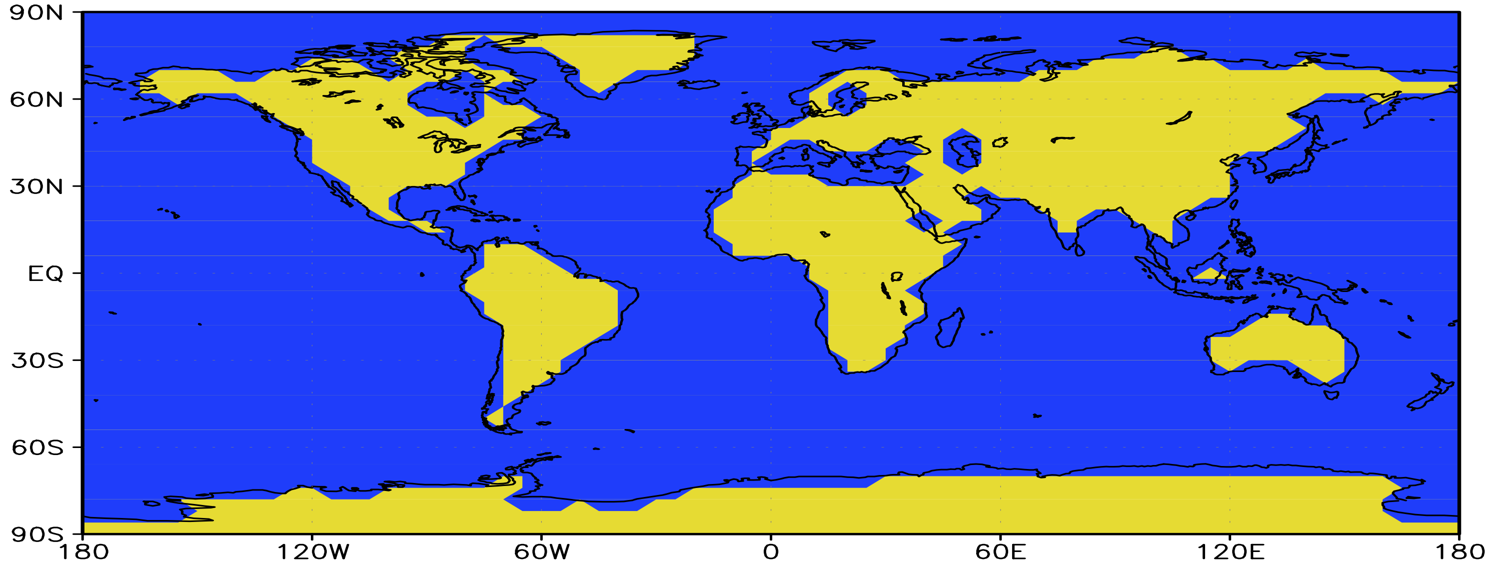
Aug.	Aug.

Topography differences between LGM and PD

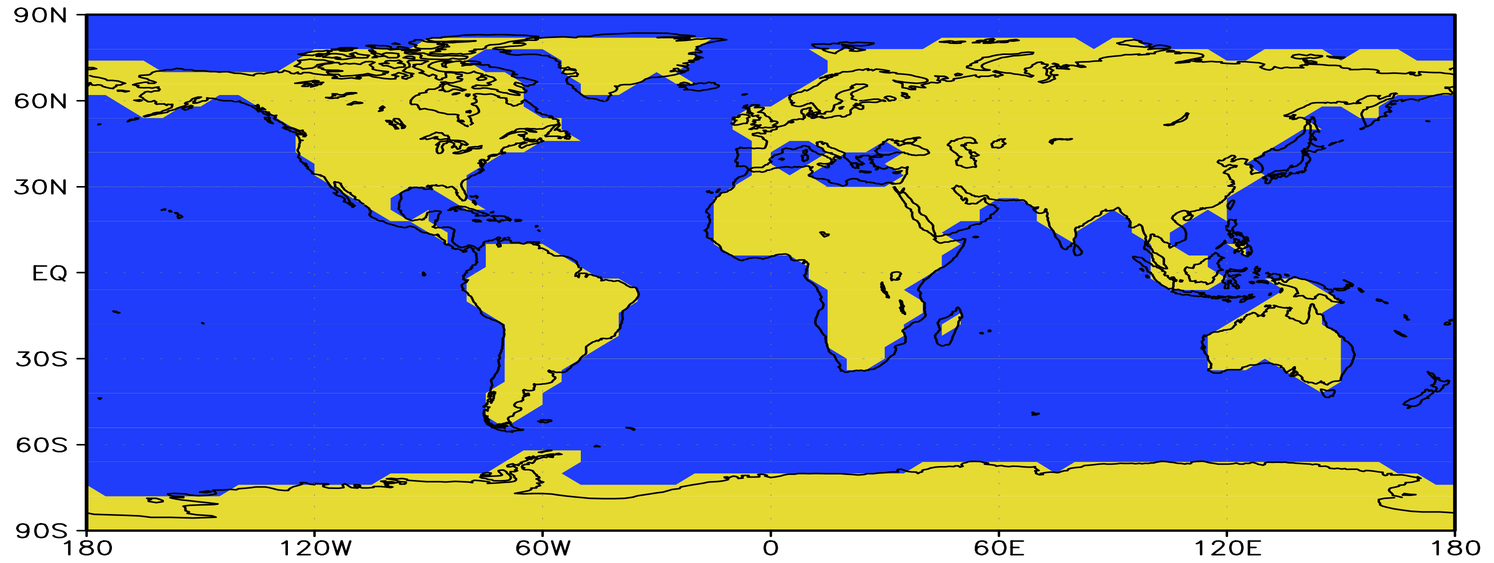


Land-Ocean Distribution

PD



LGM



SST differences between LGM and PD (Degree celsius)

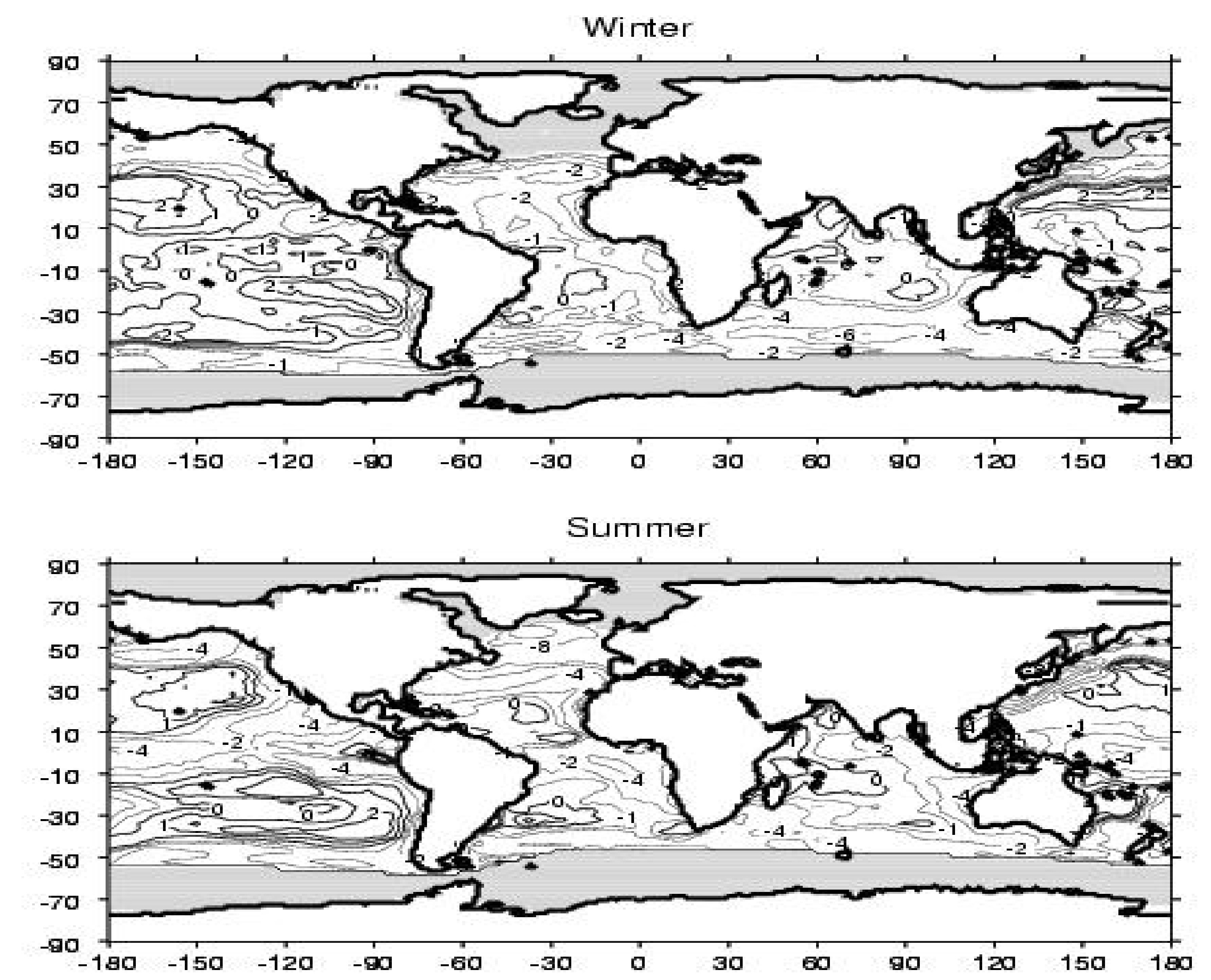


Table.2 Experimental design

Experiment	Orbital Parameters	CO_2 Level (ppmv)	SSTs, Sea ice	Ice sheets & Topography & Coastline	Vegetation
Exp1	PD	345	PD	PD	PD
Exp2	21ka	200	*CLIMAP*	*Peltier*	PD
Exp3	As Exp2, but replacing PD vegetation with LGM's over China				
Exp4	As Exp3, but replacing vegetation with Ice Sheet over part of the Tibetan Plateau				

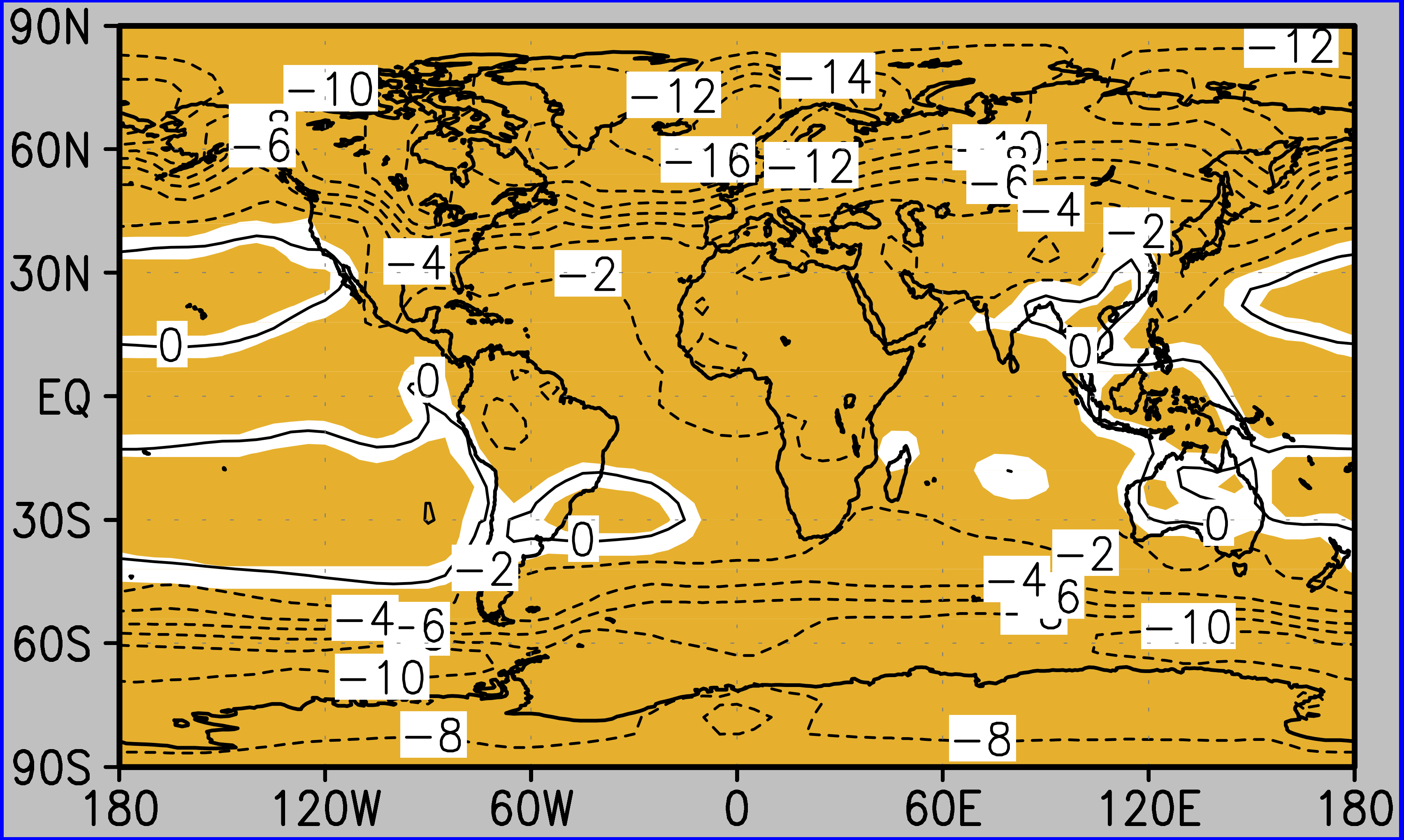
All simulations were run for 12 years starting from the same initial atmospheric circulation conditions. The results reported here are ensemble averages for the last 11 years.

3. Simulated climate differences between LGM and PD

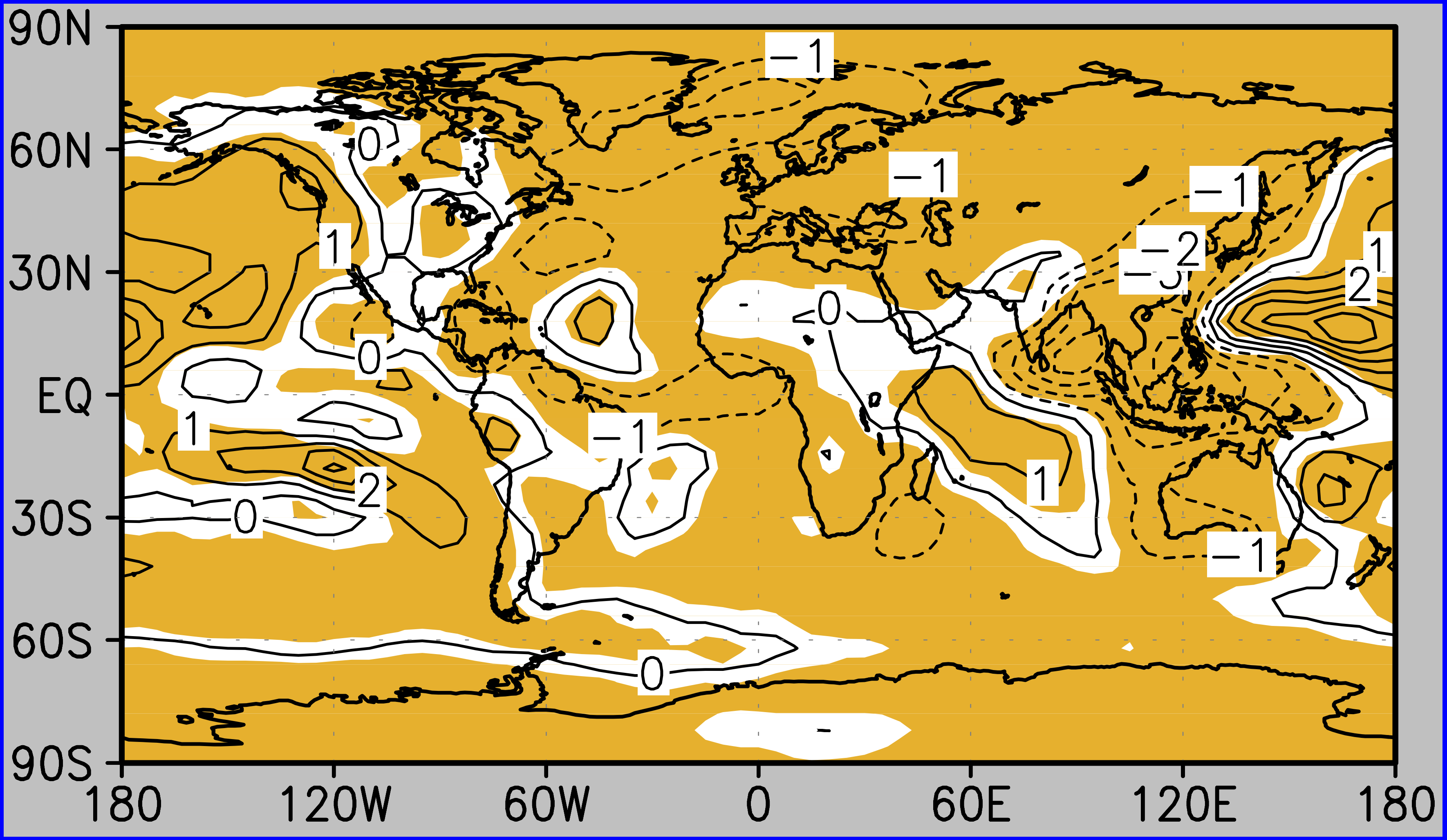
Table.3 Land temperature and precipitation changes. 21-0 means LGM minus PD (^oC); 21/0 means fractional values of LGM relative to PD

Ka	60-90^{o}N	30-60^{o}N	0-30^{o}N	0-30^{o}S	30-60^{o}S	60-90^{o}S	Global
Tem. 21-0	-11.6	-6.4	-2.2	-1.0	-1.3	-7.8	-6.4
Pre. 21/0	64%	79%	61%	76%	98%	57%	71%

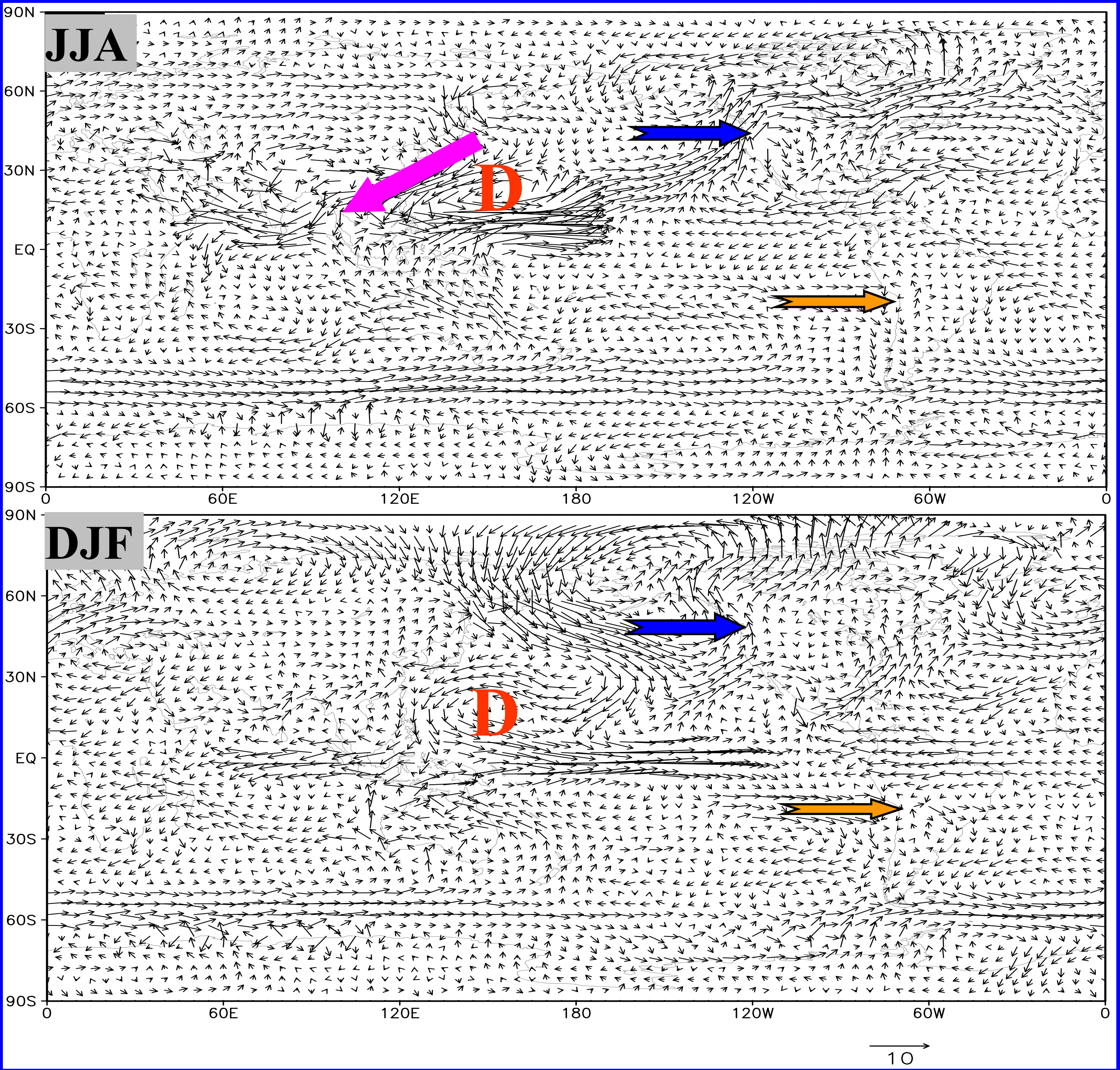
Simulated annual-mean tempreture differences (ºC) between LGM and PD



Simulated annual-mean precipitation differences (mm d^{-1}) between LGM and PD

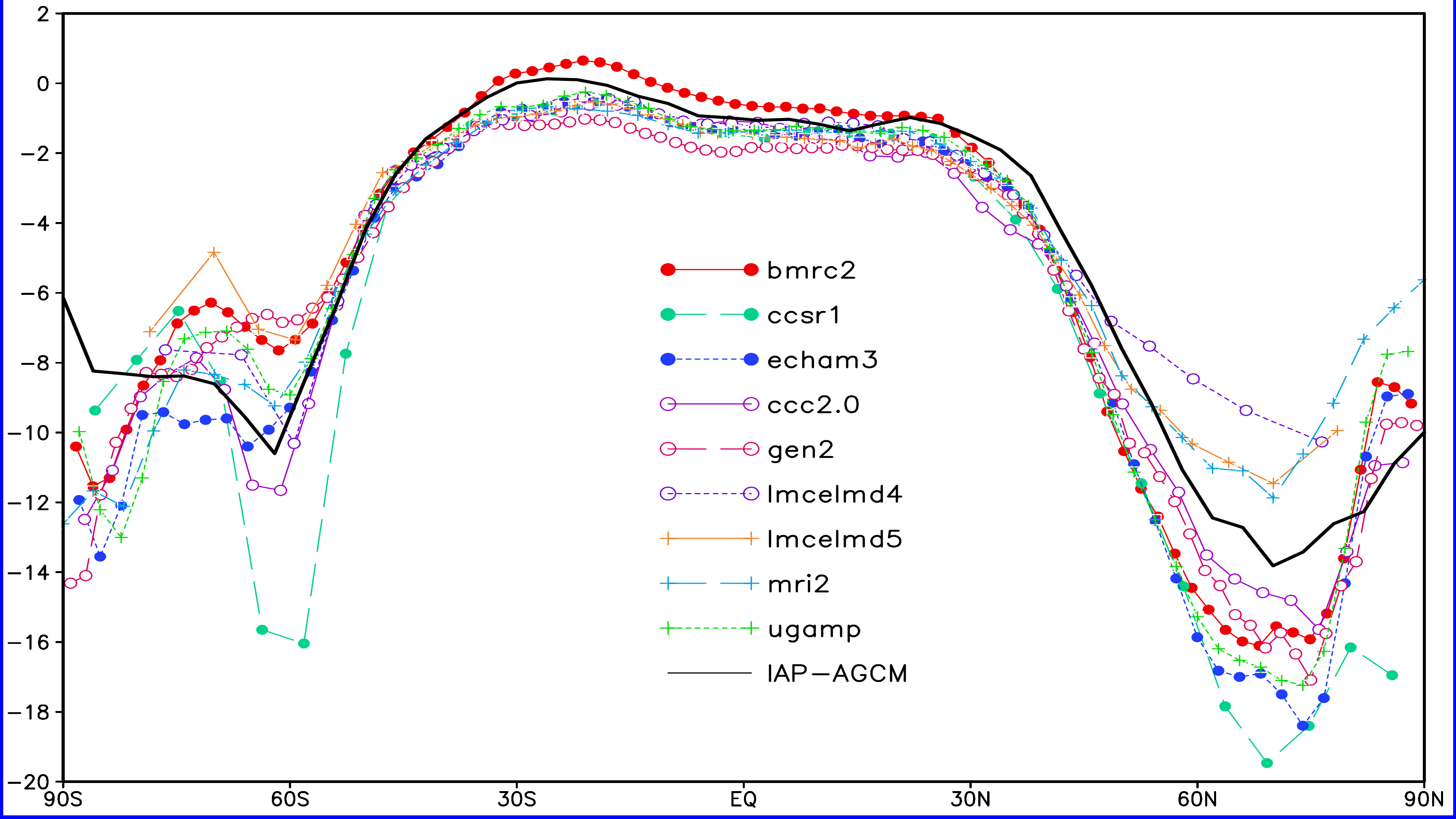


Wind Differences at 850-hPa (Unit: m/s)



4. Validation and intercomparison between AGCMs

4.1 Comparison with other AGCMs' results

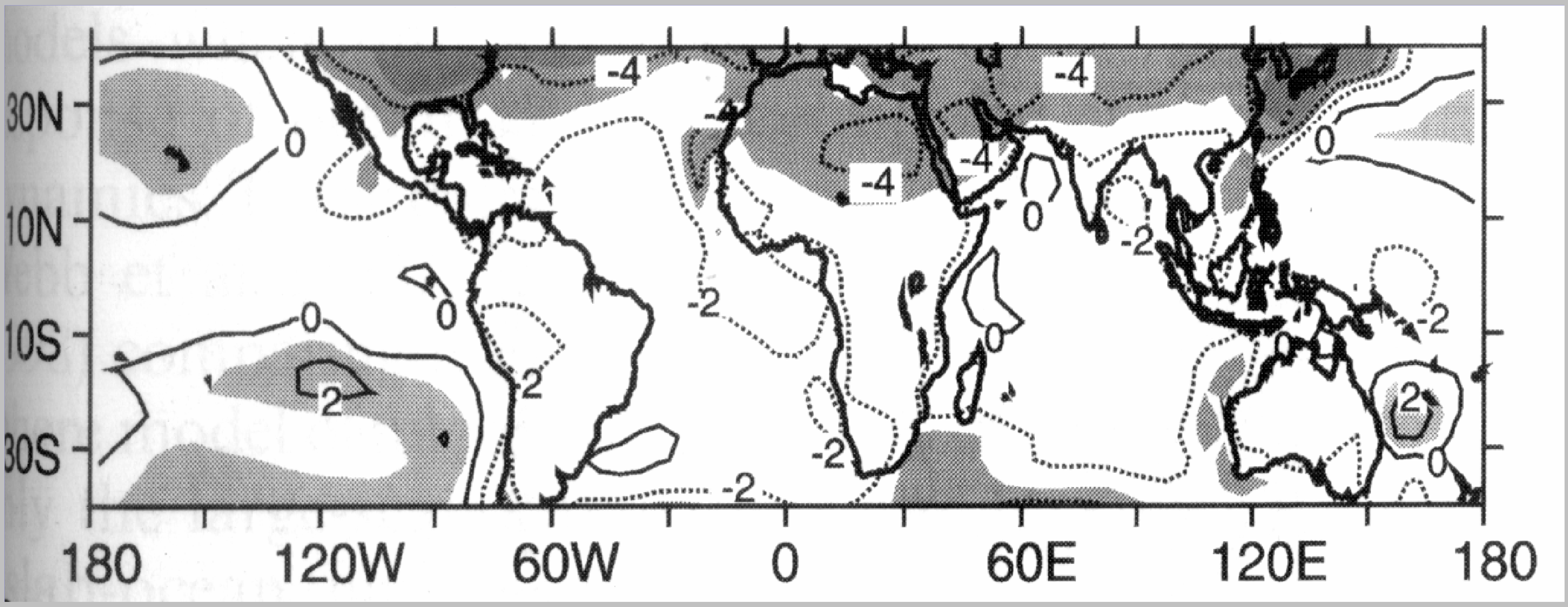


Zonally annual-mean differences in surface temperature (^{o}C) between LGM and PD simulated by the PMIP AGCMs and IAP-AGCM.

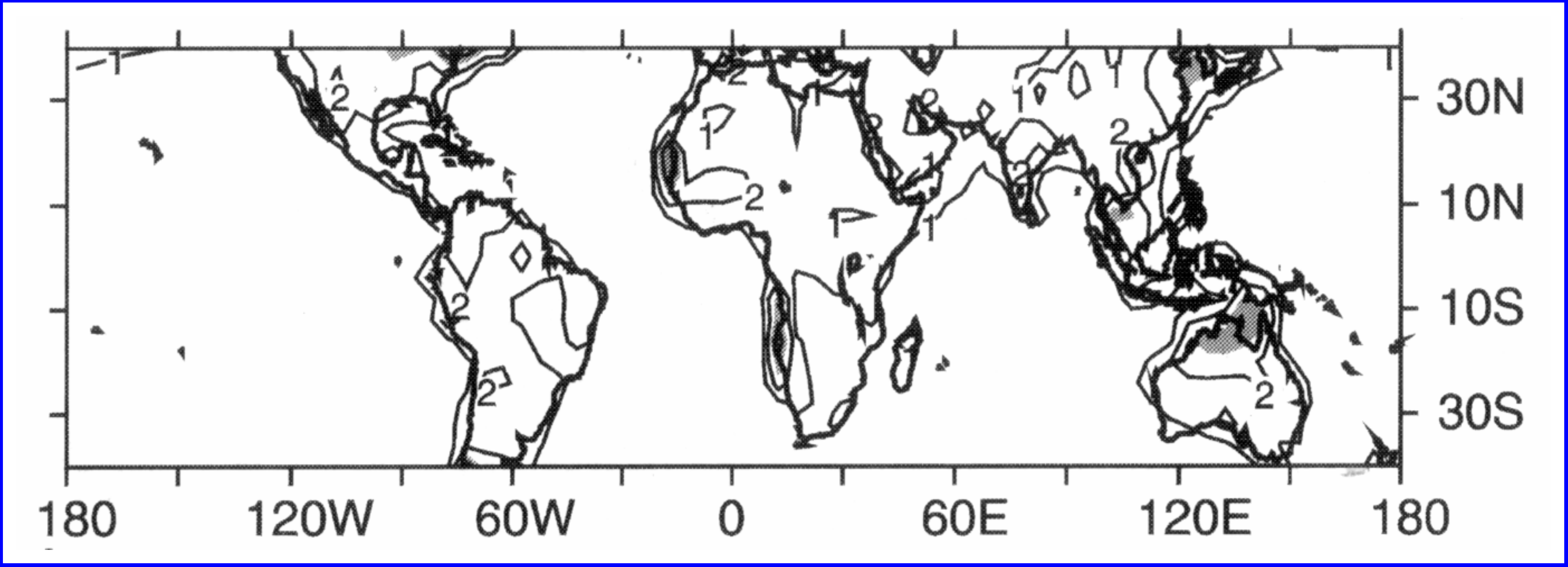
Table. 5 Changes in annual-mean precipitation (mm/day), respectively from 8 PMIP AGCMs and IAP-AGCM over terrestrial and oceanic tropics (30^{o}N-30^{o}S).

AGCMs	Precipitation over ocean	Precipitation over land
CCSR1	0.01	-0.14
ECHAM3	0.10	-0.50
GEN2	0.14	-0.65
LMD4	0.13	-0.47
LMD5	0.01	-0.30
LMDH	-0.19	-0.17
MR12	0.08	-0.58
UGAMP	0.00	-0.54
IAP-AGCM	0.02	-0.32

Composite of Simulated annual mean Temperature Differences by PMIP AGCMs (^oC) [*Pinot et al. 1999*]



Root Mean Square between pairs of PMIP AGCMs (^oC)

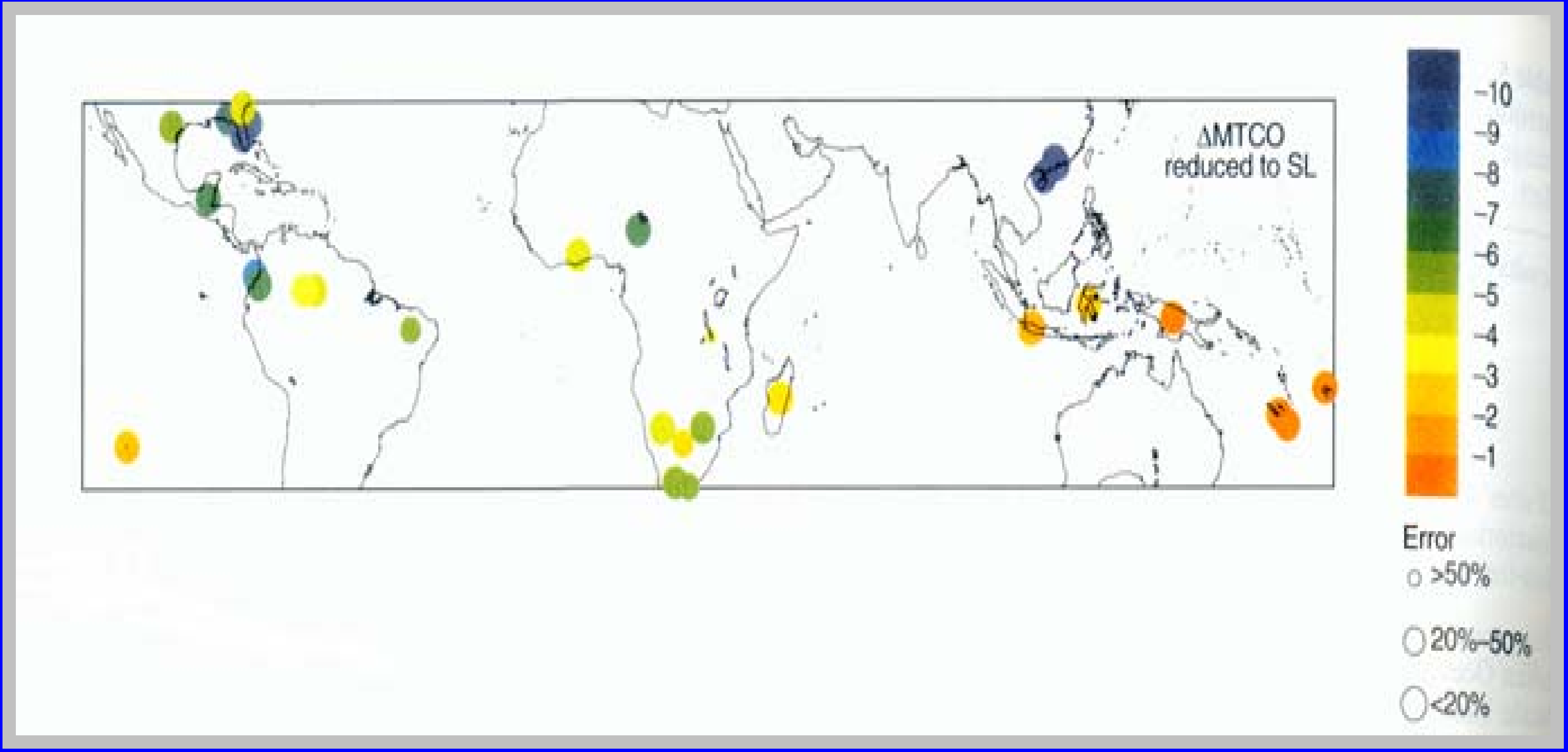


$$\sqrt{\frac{\sum_{i=1}^{n}\sum_{j=1\ \&\ j\neq i}^{n}(x_i - x_j)^2}{m}}$$

With n=number of models and m= number of pairs of models

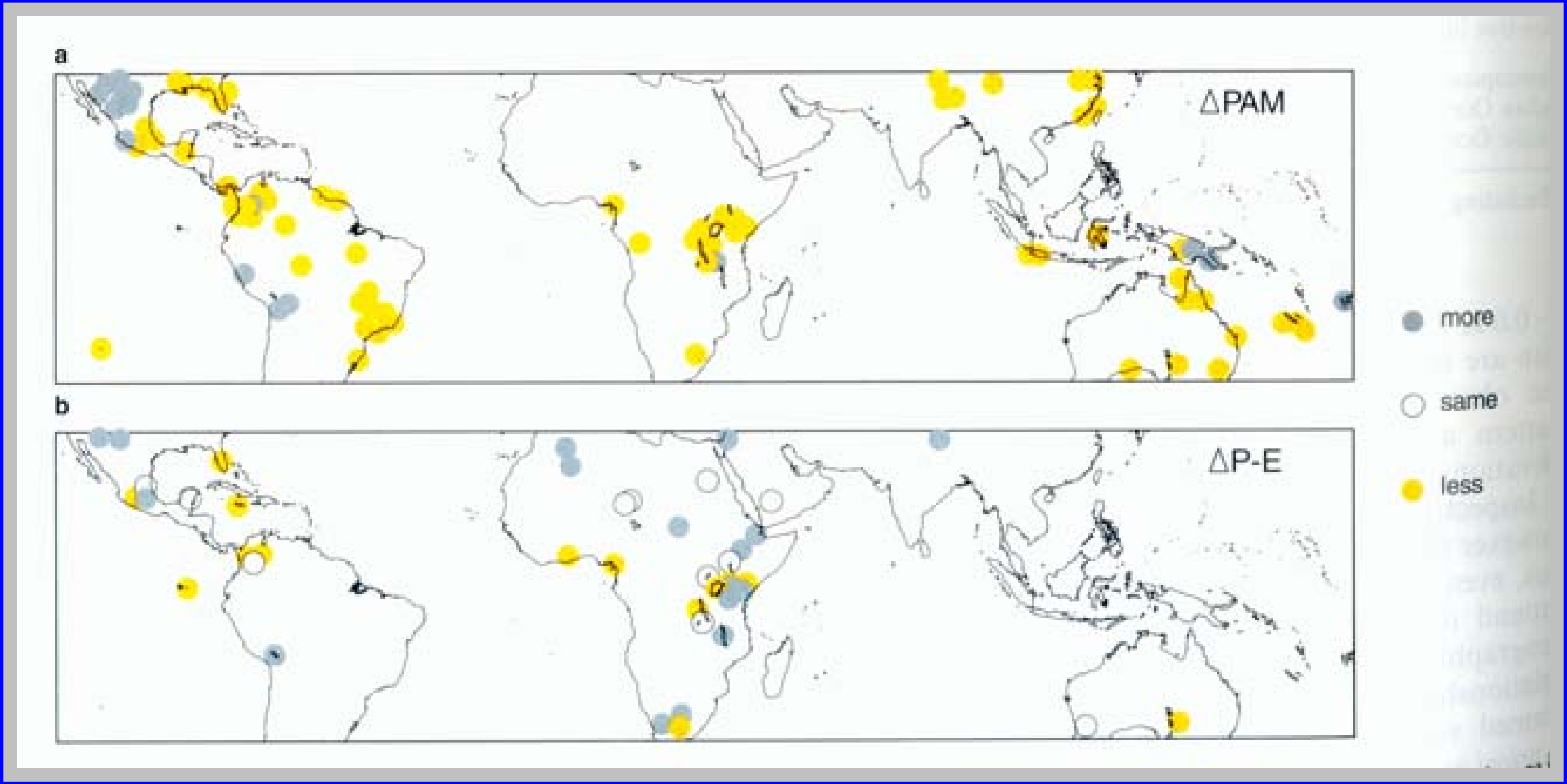
4.2 Comparison with reconstructed data

Estimated temperature anomalies of the coldest month in 32ºN-33ºS at the LGM [*Farrera et al. 1999*].



a: Directions of change in Plant-Available Moisture inferred from pollen and plant macrofossil data

b: P-E inferred from lake level reconstructions *[Farrera et al.1999]*



Observed and simulated annual mean T anomalies in the following six regions.

A: Eastern North America (75-85°W, 30-38°N) [*Farrera et al., 1999*]
B: Western North America (95-115°W, 30-38°N)
C: Northern South America (50-75°W, 10°N-2°S)
D: South Africa (15-35°E, 18-30°S)
E: Equatorial eastern Africa (25-40°E, 2°N-10°S)
F: the Tibetan Plateau (80-100°E, 30-38°N) [*Shi 1997; Yao 1998; Liu 1999*]

Regions	Proxy estimate (LGM minus PD)					IAP9L-AGCM		
	MTCO		Error	MAT	Error	MAT	SD	
	Min	Max					Exp1	Exp2
A	-7.5	-15.5	20-50%	-4	20-50%	-3.50	0.33	0.44
B				-5	20-50%	-2.53	0.38	0.47
C	-3	-6	20-50%			-1.81	0.25	0.33
D	-3.7	-6.5		-5.5	20-50%	-1.40	0.35	0.27
E	-3	-5	20-50%			-2.59	0.25	0.16
F				-9	±2	-3.54	0.22	1.02

5. Role of Paleovegetation Feedback over China

Logically, data-model discrepancies must reflect inadequacies in the formulation of the model, in the coverage and interpretation of reconstructed data, or in the specification of prescribed boundary conditions.

It has been amply documented that vegetation plays an important role in the current climate system [e.g. *Sellers et al.*, 1986].

Vegetation influences the climate, primarily through its effect on albedo, evaporation, transpiration and roughness length. The resultant changes modify both the heat exchange and water vapor content of the atmosphere [*Wyputta and McAvaney*, 2001].

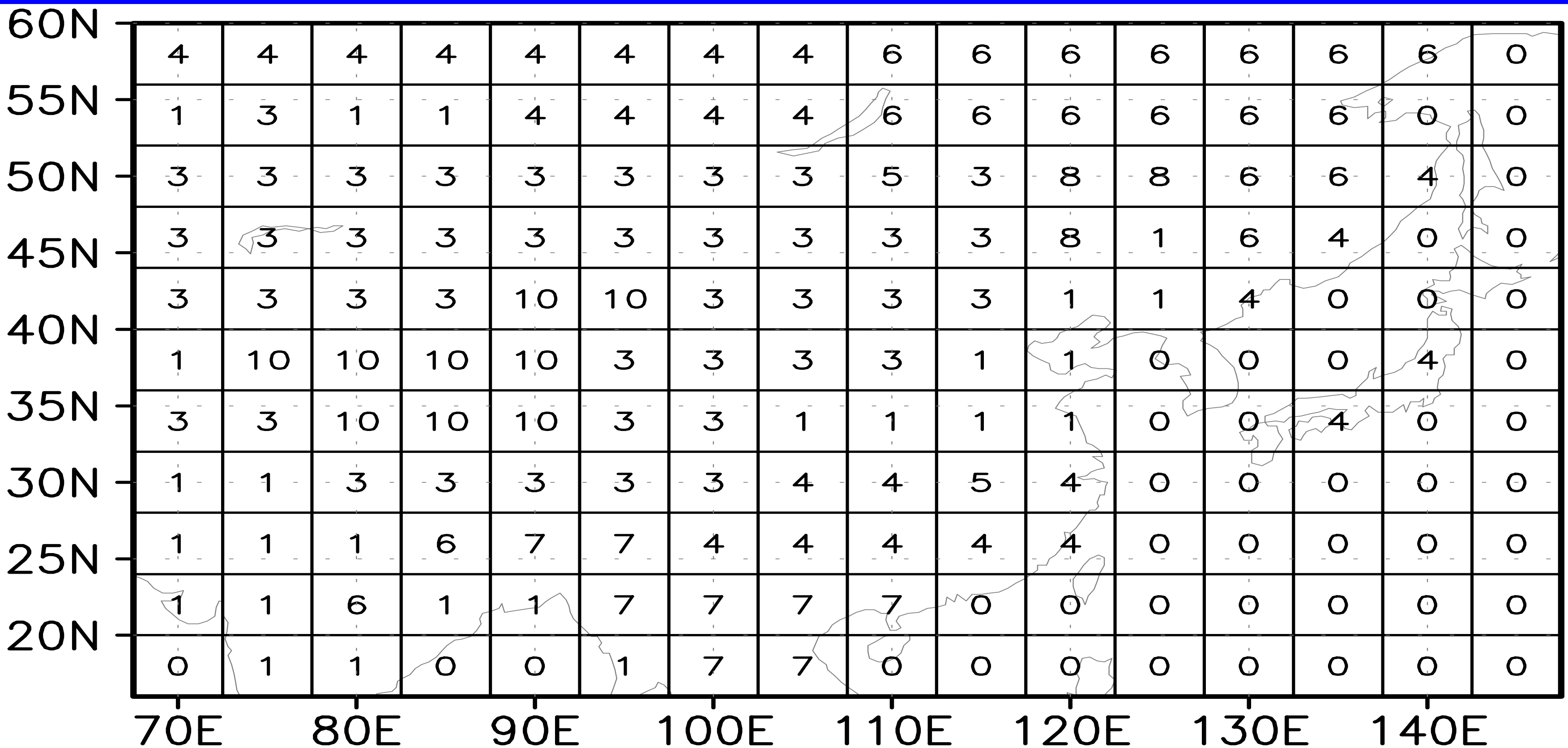
The drier-colder LGM climate is quite different from that at the PD. Climate differences must lead to changes in the surface vegetation. In return, LGM climate will change in response to vegetation changes.

However, AGCMs (some coupled to a slab ocean) used to simulate LGM climate are typically run with the PD vegetation distribution.

LGM Vegetation feedback is evaluated by *Crowley and Baum* [*1997*], *Wyputta and McAvaney* [*2001*], *Kubatzki and Claussen* [*1998*], and *Levis et al.* [*1999*] with reconstruction or biome model, and show inclusion of "realistic" vegetation generally leads to additional cooling in some regions and, therefore, reduces, to a certain degree, data-model disagreements. Then, what is the role of paleovegetation feedback on the LGM climate over China?

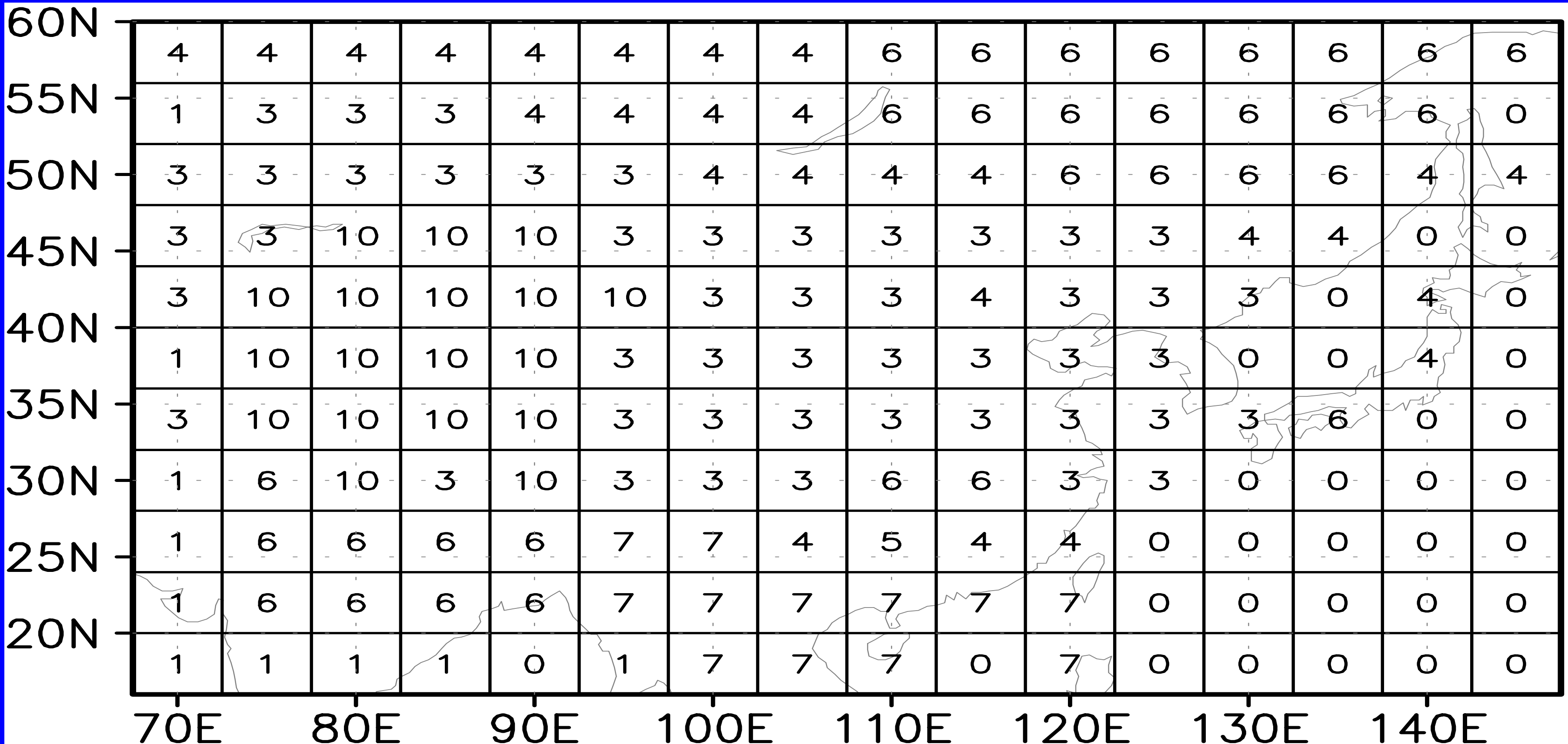
Here, we used the LGM paleovegetation reconstructed by *Yu et al.* [*2000, 2001*] in the range of 22°-54°N, 75°-135°E. Also, soil color index associated with surface vegetation is changed.

Surface vegetation at PD



1. mixed farming, tall grassland,
2. tall/medium grassland, evergreen shrub-land
3. short grassland, meadow & shrub-land
4. evergreen forest (needle-leaved)
5. mixed deciduous, evergreen forest
6. deciduous forest
7. tropical evergreen broadleaved forest
8. medium/tall grassland, woodlands
9. tundra
10. **desert**

Surface vegetation at LGM



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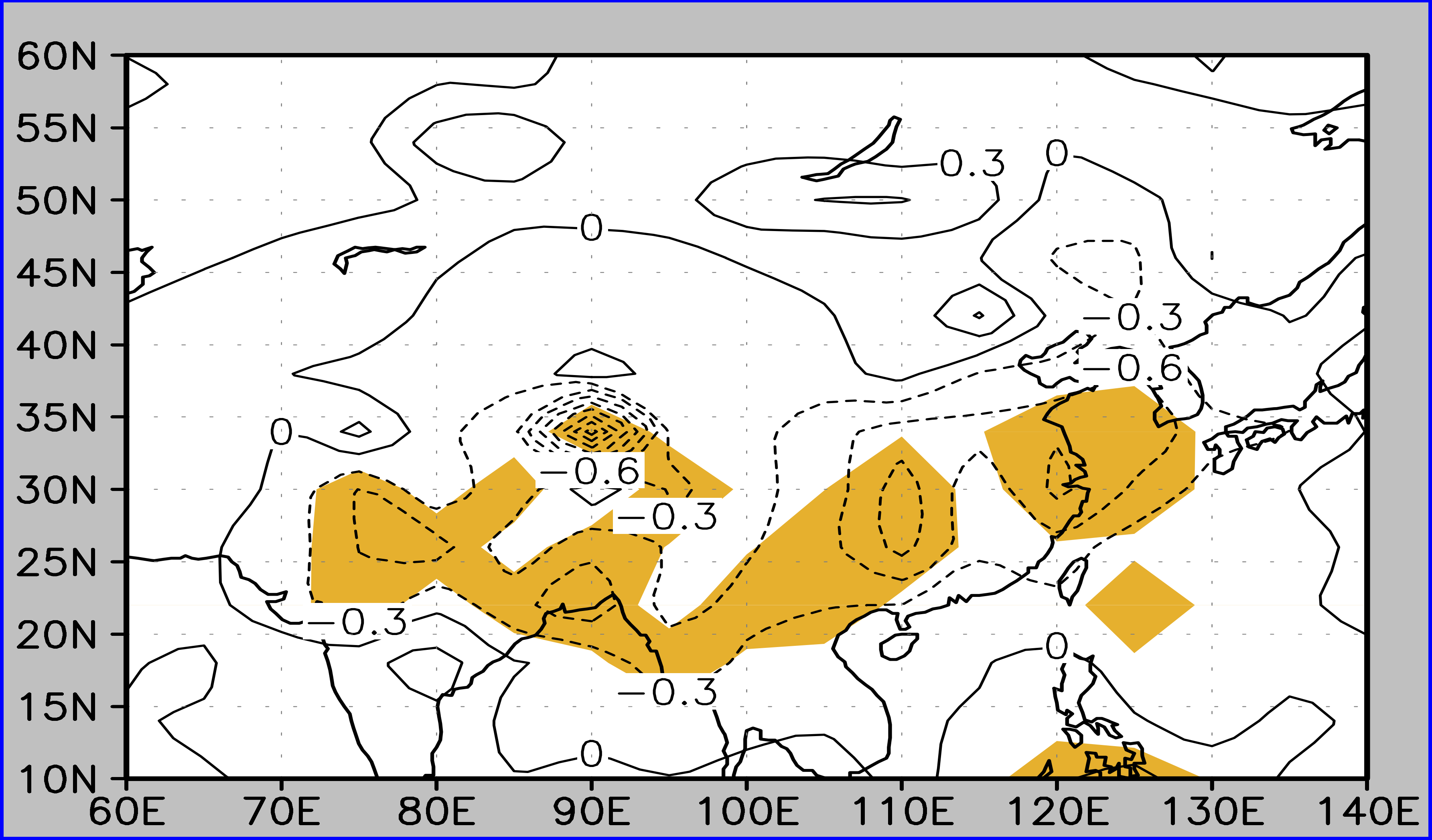
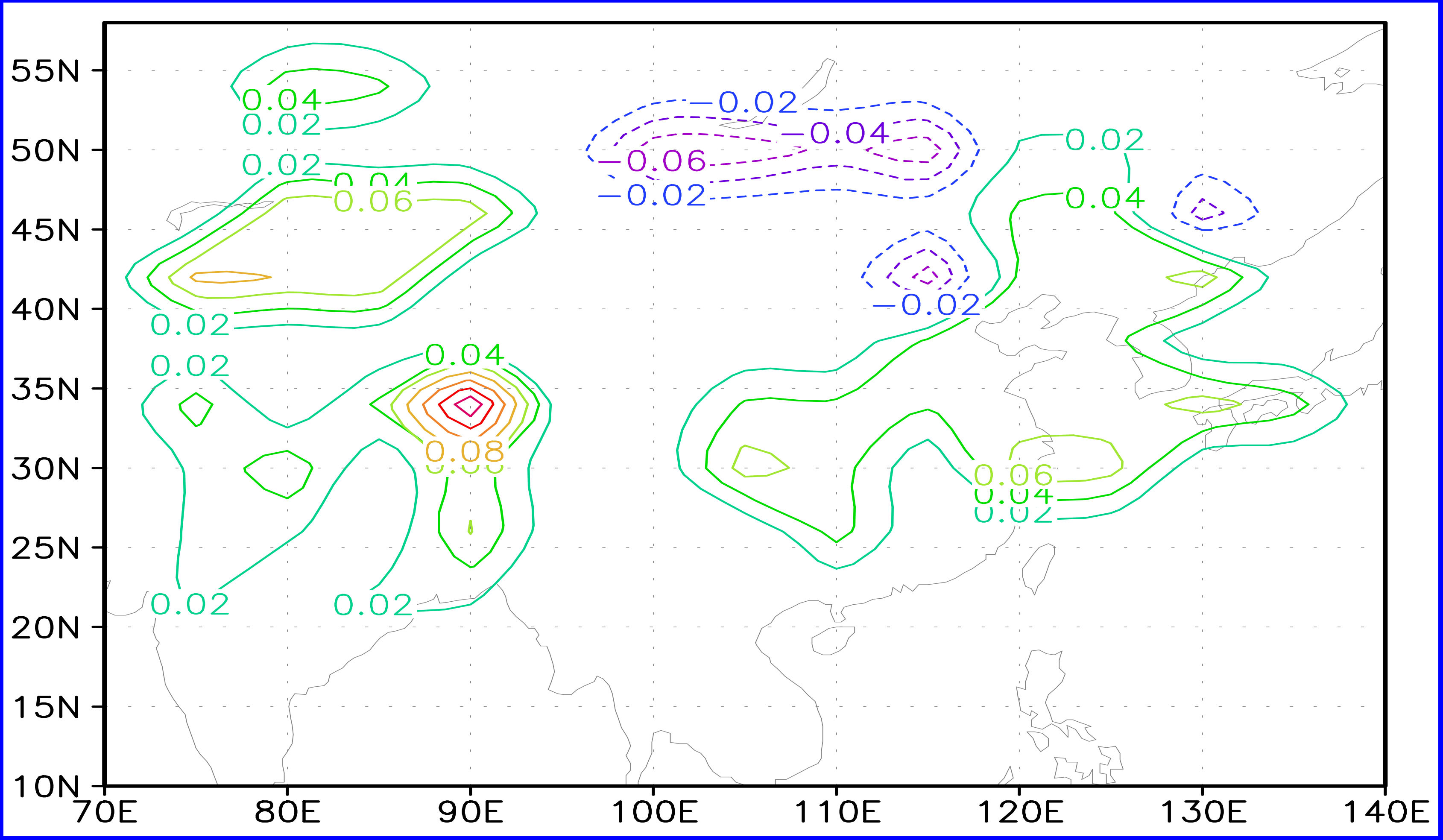
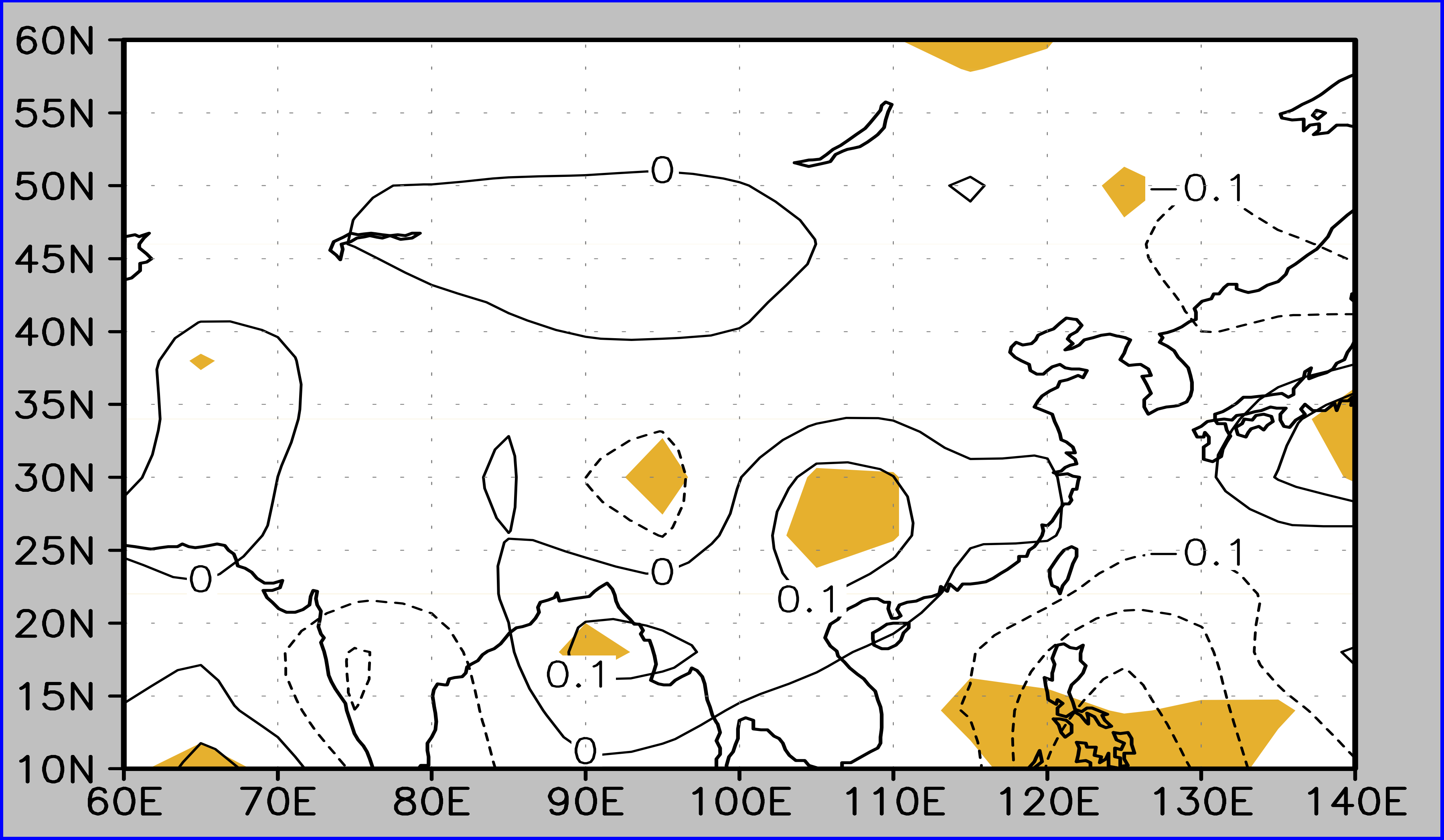
Temperature changes (ºC) caused by LGM Paleovegetation



Annual mean anomalies (Exp3 minus Exp2) of albedo.



Precipitation changes (mm day^{-1}) caused by LGM Paleovegetation



6. Role of Continent Ice Feedback

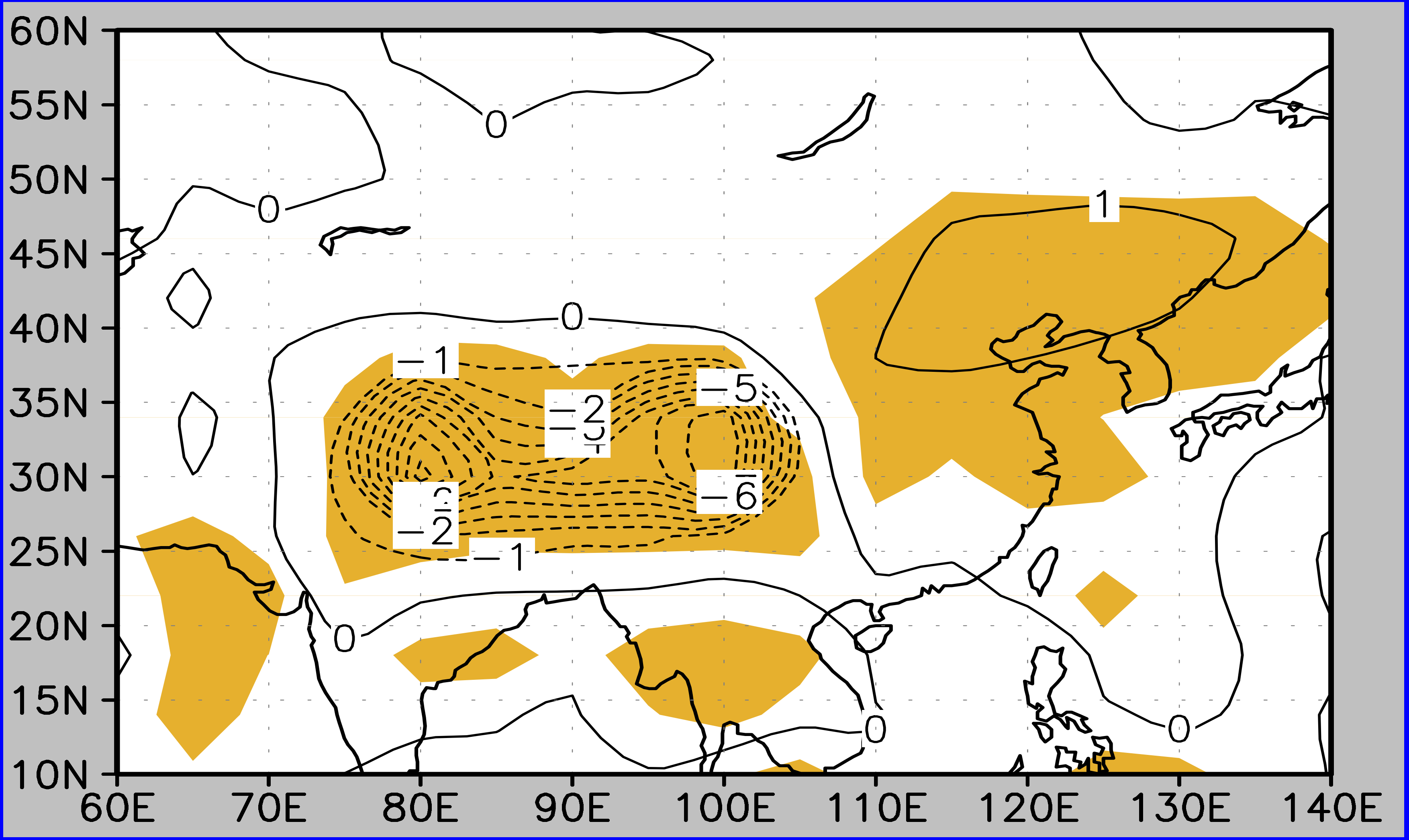
Controversies on the glacial-age environment over the Tibetan Plateau have always been kept among scientists [*Huntington 1906; Kuhle 1987, 1991; Han 1991; Shi 1997, and so on*].

***Liu et al.* [*1999*] studied vegetation response to climate changes over China with a 'Taiji system' developed and validated by them. Results indicated a large range of continental ice would exist over the Tibetan Plateau under the cooling by 5-9^{o}C, even if moisture amount keep invariable. They finally concluded a large range of continental ice possibly existed there at LGM.**

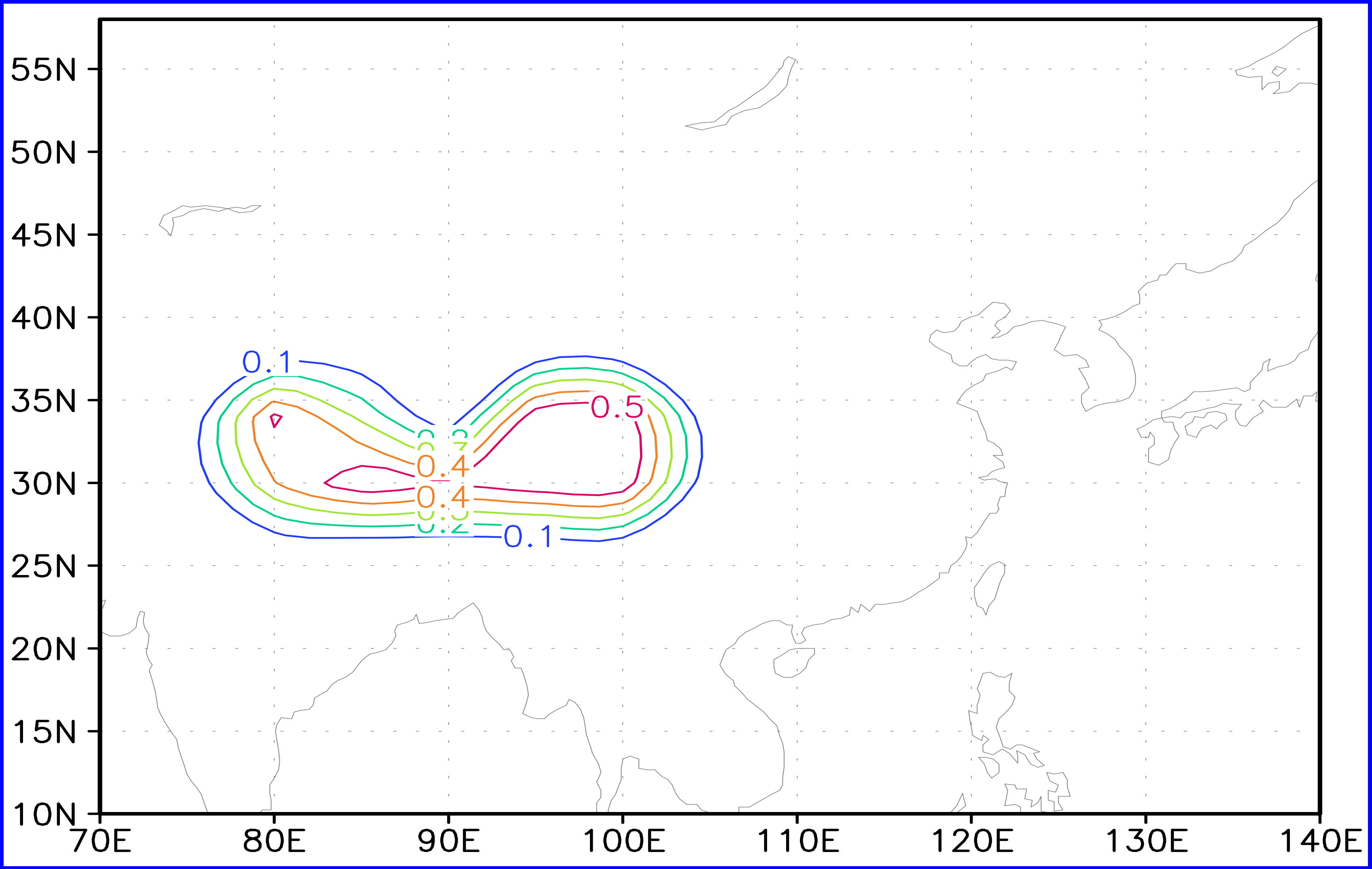
Recently, the same conclusion was reached when *Jiang et al.* [*2002*] simulating the potential LGM vegetation distribution over China using the process-based equilibrium terrestrial biosphere model BIOME3 [*Haxeltine and Prentice, 1996*].

With the debate still in progress, Exp.4 is designed on the basis of above Exp.3 , in which continental ice appeared in the range of 30^{o}-34^{o}N, 80^{o}-100^{o}E [*Liu et al. 1999*].

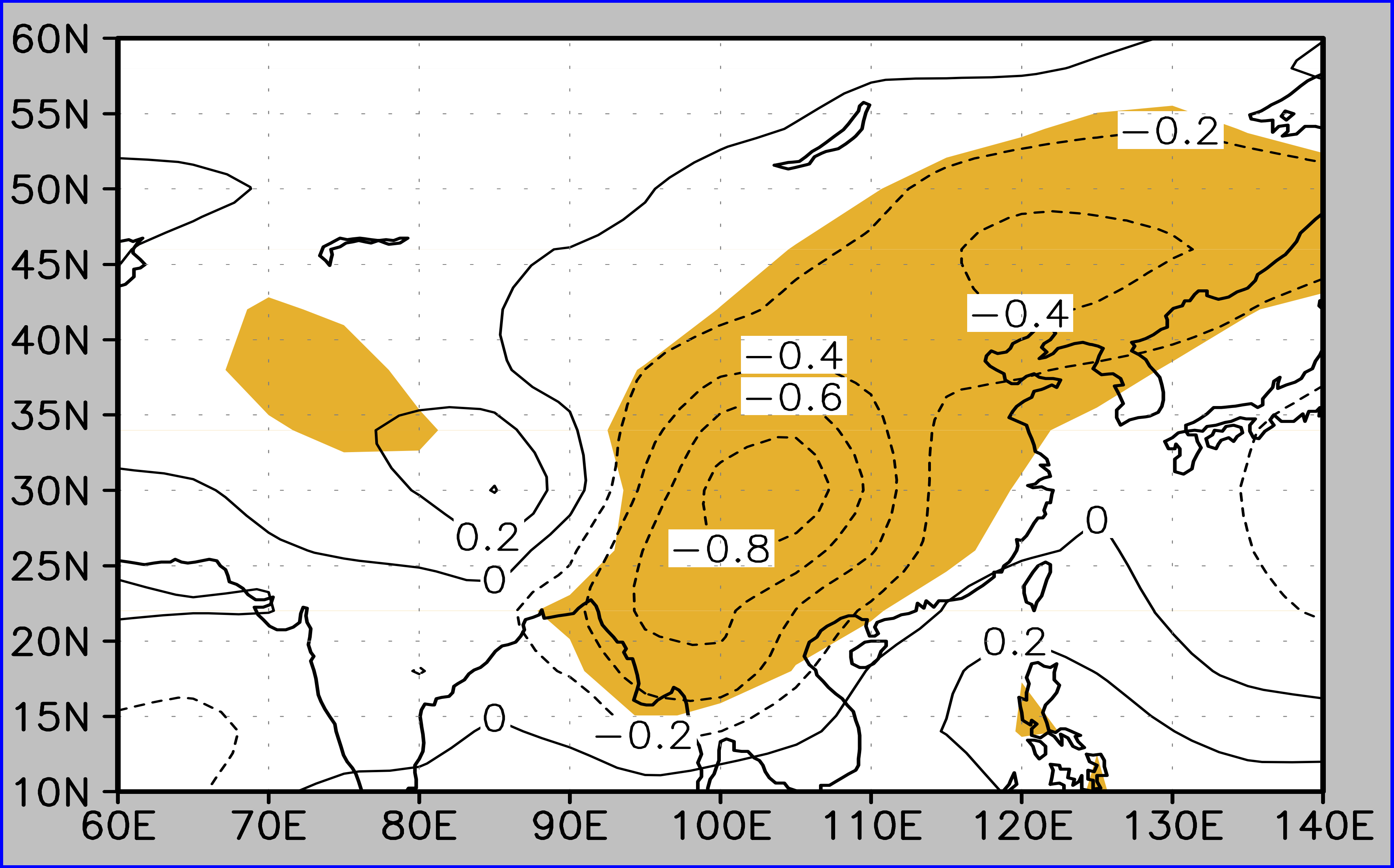
Temperature changes (ºC) caused by the continental ice over part of the Tibetan Plateau



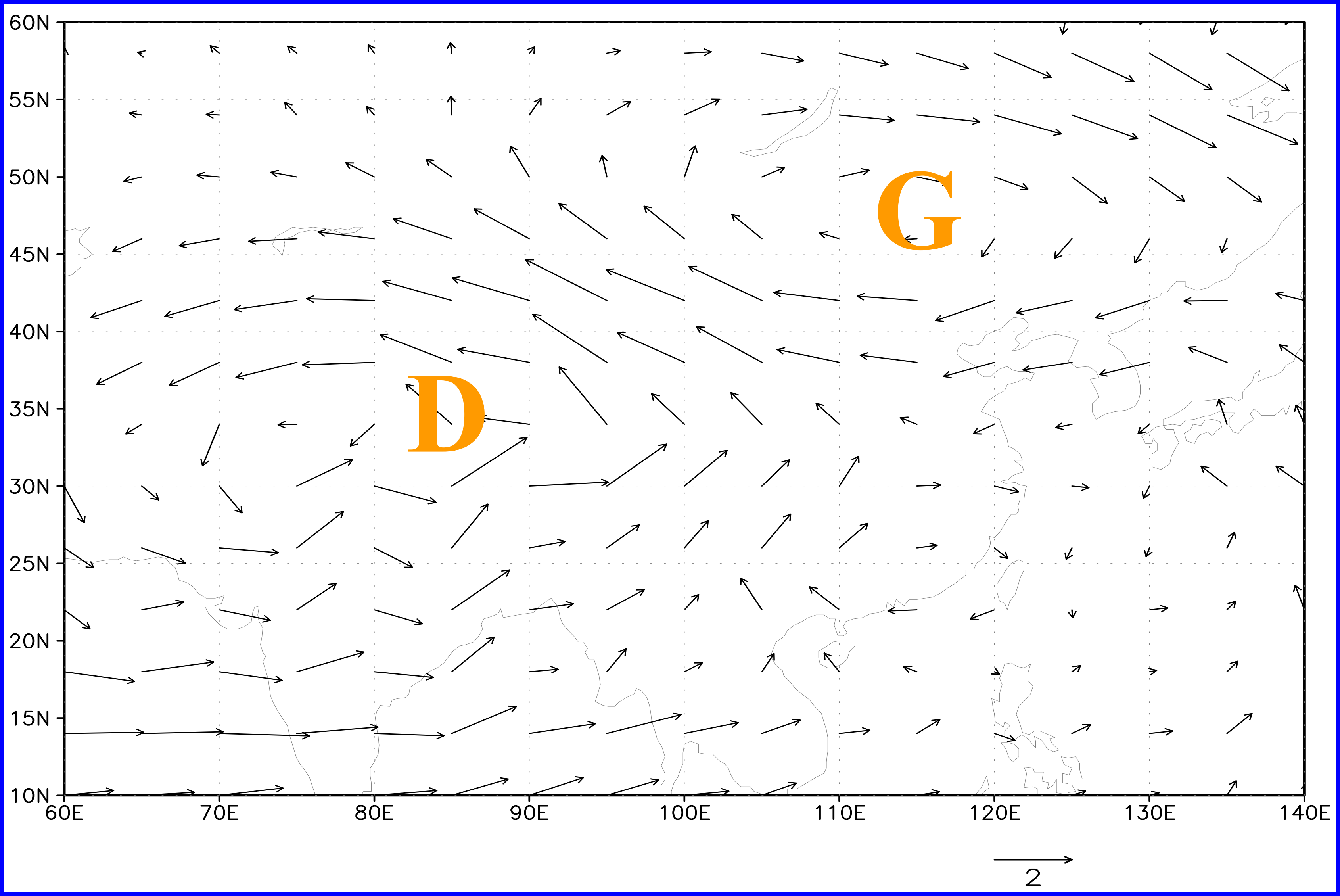
Annual mean anomalies (Exp4 minus Exp3) of albedo



Precipitation changes (mm/day) caused by the continental ice over part of the Tibetan Plateau



JJA wind diffences (Exp4 minus Exp3) at 200-hPa (m/s)



Summary

- At the LGM, the global annual mean surface temperature decreased by 5.3^{o}C, while terrestrial temperature reduction reached 6.4^{o}C compared with the PD. The cooling gradually decreased from the polar regions toward the tropics, and was larger in the northern hemisphere. Moreover, terrestrial cooling generally surpassed oceanic cooling in tropics.

- Drier climate dominated at the LGM. Global annual mean precipitation was found to be 91% of the PD value. Terrestrial precipitation accounted for only 71% of the PD value. In contrast, wetter conditions were registered in western North America, in Arabia, and over the Andean Altiplano.

- **Additional cooling due to the changes in vegetation and associated soil characteristics generally reduces, to a certain degree, model-data discrepancies over China.**

- **Study of the role of continental ice feedback over the Tibetan Plateau indicates that if continental ice indeed existed at the LGM, its influence on the 21 ka climate would be very distinct in East Asia.**

Thank you!